Innovation Report

Physiological and Biomechanical Testing of EasyPedal Pedal Prototypes

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1. Introduction

Cyclists are continuously pursuing new training methods and strategies in an attempt to improve performance [1]. To date most research has focused primarily on metabolic factors such maximal oxygen consumption (VO_{2max}) and blood lactate thresholds as these have been repeatedly shown to predict performance [2, 3]. Nonetheless, an often overlooked and arguably more important factor is cycling economy, which is defined as the submaximal oxygen demand per unit of body mass required to perform a given task [4]. The economical transfer of power from the human body to mechanical power output driving the bicycle is influenced by many aspects of equipment configuration and the pacing strategy employed. Accordingly, manipulations of seat height [5, 6], seat-tube angle, pedal cadence [7], chainring design [8, 9], crank length [10, 11], and the pedal design [1, 10, 12] have all been investigated.

Mechanical power is the product of torque and pedal velocity and has been shown to be a key determinant of cycling performance [13]. Torque is the product of the force applied perpendicular to the crank arm and the crank arm length [14]. Although constant torque production would optimise performance, anatomical and gravitational constraints mean that torque is actually produced in a nearly sinusoidal manner with minimal torque being produced when the crank is positioned vertically [15]. Consequently, any strategy that could potentially optimise the crank cycle warrants further consideration. Increasing the length of the crank arm during the downward stroke of the cycle has been shown to produce the highest torque values [15] and has subsequently lead to the design of non-circular chainrings to theoretically achieve such an effect. Nonetheless, the results of the experimental studies to date that have used such an approach could best be described as equivocal [8, 11].

An alternative method to achieve an increase in the crank arm during the downstroke is to potentially modify the foot pedal. The pedal is the terminal point of force transmission and throughout cycling history it has been subject to substantial research and development with a view to improve its design features [1]. Pedals have evolved from the classic loose pedal-shoe contact to a modern lightweight type with tight-cleat fixings. The EasyPedal™ has been designed with the express intention of increasing the crank arm length during the critical downstroke period. To achieve this mechanical advantage, the EasyPedal prototypes feature lengthened conventional pedals and added an incline. The pedal design only allows anti-clockwise rotation around the crank arm to facilitate pedalling and to allow the additional pedal length to temporarily lengthen the crank arm. Therefore, the aim of the proposed study is to assess the effects of the EasyPedal compared to a conventional pedal on measures of cycling efficiency in a group of recreational cyclists.

2. Methods

2.1 Main study methods

Participants

Fourteen apparently healthy, recreationally active volunteers 9 male and 5 female (Mean ± SD: age 38.2 ± 10.4yrs; height 174.8 ± 6.81cm; body mass 76.2 ± 9.3 kg; max heart rate 182 ± 10.4 beats/min) completed this study. The experimental procedure and nature of risks were explained to all participants. A pre-test questionnaire and informed consent was obtained and reviewed prior to testing. All procedures were approved by the Research and Ethics Committee of the University of Ulster.

Experimental Design

The study consisted of a single testing protocol at a laboratory on two separate days (3-10 days apart) to examine the EasyPedal (EP) prototype pedal or conventional pedal. The order of pedal was randomized and counter-balanced across the two days. All participants were familiarised with all testing procedures prior to experimental trial. All trials were performed at the same time of day to negate diurnal variation. Participants were required to follow their "usual" diet, and record all foods consumed 24 hours prior to their first experimental trial. The same diet then was consumed before the second trial. To facilitate compliance, diet sheets were given to each participant, which were brought to the first trial, photocopied, and returned to the participant to ensure replication. Participants were required to refrain from strenuous activity for at least 24 hours prior to each testing day. The testing schedule is illustrated in Figure 1.

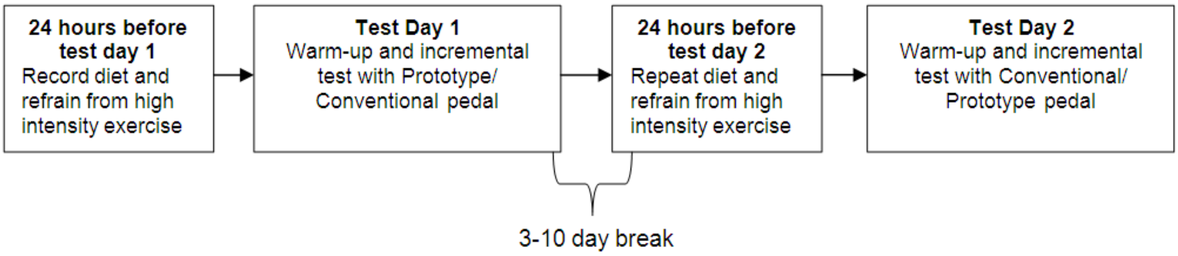

Figure 1: Testing schedule for participants. Eight participants will use the prototype pedal on test day 1, followed by the conventional pedal on test day 2. The other eight participants will use the conventional pedal on day 1 followed by the prototype pedal on day 2.

Data Collection

The testing session consisted of a 10 minute warm-up at 90 watts, using either the prototype or conventional pedal. Midway through the warm-up, an oxygen mask was securely fitted to participant. Oxygen consumption was recorded after 7 minutes into the warm-up and was continually monitored using a Cosmed Quark CPET system (Cosmed, Italy). This system was calibrated for volume on each test day and for gas content during each test session. Participants completed an incremental protocol beginning at 120 watts and increased by 30 watts after each 4-minute phase (using the same pedal set-up as in the warm-up). Once the 210 watt phase was completed or when participants reached 90% of their estimated heart rate maximum (HRM), the test was terminated.

All testing was completed on a Felt bicycle attached to an electrically braked cycle ergometer (T1980 Bushido Trainer, Tacx, Holland). A brake calibration was completed for each testing session. Participants self-selected their seat height until they were comfortable. A manual measurement was recorded to ensure an identical seat height for the second trial. Heart rate (HR) was recorded continuously during each trial by means of ECG calibration telemetry using the RS 400 (Polar Electro OY, Kempele, Finland). Preceding the first visit to the laboratory, participant's body mass and height were measured to the nearest 0.1kg and 0.1cm, respectively, (Seca Delta-Model 707, Cardiokinetics, UK). Laboratory temperature was controlled at 17 degrees for all trials.

In addition, qualitative data was captured of the medial sagittal plane of the lower limb using a Panasonic VDR-D51 video camera at 50 Hz. Video data was recorded after 8 minutes of the warm-up, and midway through the 150 and 210 watt phases for a duration of 30 seconds.

Data Analysis

Data was collected during the last 2 minutes of each 4 minute phase including the warm-up. Wireless data was received from the ergometer via an infrared dongle (Tacx, T1991) connected to a PC using Tacx trainer software (3.4.0).

Statistical Analysis

Oxygen consumption, heart rate and power output were assessed using a repeated measures ANOVA with two within subject factors (pedal type and intensity) in SPSS Statistics 17.0. An alpha level of $p<0.05$ was used throughout to indicate statistical significance.

2.2 Case study 1 methods

One healthy recreationally active male (age 31 years, mass 88 kg, height 1.95 m) participated in this study. The experimental procedure and nature of risks were explained to the participant. A pre-test questionnaire and informed consent was obtained and reviewed prior to testing.

The case study was carried out over two test days (8 days apart). On the first test day, the participant carried out an 18 minute cycling test using the EP pedals followed by a 2-hr rest period and then repeated the 18-min cycling test using conventional pedals. On the second test day the procedure was repeated, however the order of pedals used was reversed (now Conventional pedals - 2-hr rest - EP pedals). The 18-min cycling test consisted of 10 minutes at 90 watts, followed by 4 minutes at 120 watts and 4 minutes at 150 watts. This was carried out using the same ergometer set-up as described in the main study. However, in the case study the participant sat in a modified semi-recumbant position behind the typical saddle position (see Figure 2).

Figure 2: Semi-recumbant set-up during EasyPedal testing in case study 1

The data analysis was identical to the main study, with heart rate and video footage recorded, however the video footage was recorded using a Casio Ex F1 at 300 Hz. No inferential statistical analyses were conducted on the case study 1 results.

2.3 Case study 2 methods

One healthy recreationally active male (age 31 years, mass 88 kg, height 1.95 m) participated in this study. The experimental procedure and nature of risks were explained to the participant. A pre-test questionnaire and informed consent was obtained and reviewed prior to testing.

The case study was carried out over two test days (5 days apart). On the first test day, the participant carried out a 16 minute cycling test using conventional pedals followed by a 2-hr rest period and then repeated the 16-min cycling test using the EP pedals (new prototypes – different than those used in both the main study and case study 1). On the second test day the procedure was repeated, however the order of pedals used was reversed (now EP pedals - 2-hr rest - Conventional pedals). The 16-min cycling test consisted of 7 minutes at 90 watts, followed by three 3-min stages at 150 watts, 180 watts and 210 watts. This was carried out using the same semi-recumbant set-up as described in case study 1.

Again, the data analysis was identical to the main study, with heart rate and video footage recorded, however the video footage was recorded using a Casio Ex F1 at

300 Hz. No inferential statistical analyses were conducted on the case study 2 results.

3. Results

3.1 Main study results

No statistically significant differences were detected in oxygen consumption (p=0.521), heart rate (p=0.537) or power output (p=0.222) between the two pedal types (Table 1). Changes in intensity did have a significant effect on oxygen consumption, heart rate and power output (all p<0.01) as expected, with increasing intensity causing increases in all three variables.

Table 1: Mean power output, heart rate and oxygen consumption for all cycling intensities

Phase	Power (Watts)		Heart Rate (bpm)		Oxygen Consumption (ml/kg/min)	
Time (min)	EP	Conventional	EP	Conventional	EP	Conventional
8-10mins (90 watts)	99.89	98.53	112.53	107.28	19.79	20.53
12-14mins (120 watts)	120.98	120.40	125.36	121.92	23.49	23.46
16-18mins (150 watts)	148.02	149.96	139.76	135.64	27.23	27.60
20-22mins (180 watts)	175.20	175.19	146.18	143.47	32.08	32.24
24-26mins (210 watts)	201.52	202.18	154.54	152.75	35.31	35.75
Mean	149.12	149.25	135.67	132.21	27.58	27.92

3.2 Case study 1 results

Due to the effects of fatigue (causing increases in heart rates during the second half of each test day), the case study results are analysed by comparing pedals types against each other based on the time during the test day that they were used. Therefore, Table 2 illustrates the comparison of pedal types when used at the beginning of the test day and Table 3 compares the pedals when used in the second half of each test day. The results indicate no clear benefit (reduced exertion) of the EasyPedal prototypes in this semi-recumbant set-up. In fact, the conventional pedals tend to show slightly lower heart rates (1-3 bpm) at the same absolute intensity.

Table 2: Pedal type results when used during first half of test day (Case study 1). Negative values for differences indicate that the EP value is higher

	Power (Watts)	Cadence (rpm)	Heart Rate (bpm) Average
Conventional Pedal			
8-10mins (90 watts)	91	75	93
12-14mins (120watts)	120	75	104
16-18 mins (150 watts)	150	74	116
Easy Pedal (EP)			
8-10mins (90 watts)	93	74	96
12-14mins (120watts)	120	75	104
16-18 mins (150 watts)	150	74	117
Difference (Conventional-EP)			
6-7 mins (90 watts)	-1	0	-3
9-10 mins (150watts	0	1	0
12-13 mins (180 watts)	0	0	-1

Table 3: Pedal type results when used during second half of test day (Case study 1). Negative values for differences indicate that the EP value is higher

	Power (Watts)	Cadence (rpm)	Heart Rate (bpm) Average
Conventional Pedal			
8-10mins (90 watts)	90	69	99
12-14mins (120watts)	120	68	110
16-18 mins (150 watts)	150	70	121
Easy Pedal (EP)			
8-10mins (90 watts)	90	72	101
12-14mins (120watts)	120	72	109
16-18 mins (150 watts)	150	73	123
Difference (Conventional-EP)			
6-7 mins (90 watts)	0	-4	-2
9-10 mins (150watts	0	-4	1
12-13 mins (180 watts)	0	-2	-2

3.3 Case study 2 results

Based on a similar analysis approach to Case Study 1, the results indicate no clear benefit of the EasyPedal prototypes in this semi-recumbant set-up (Tables 4 and 5). Conversely the conventional pedals tend to show lower heart rates (0-8 bpm) at the same absolute intensity.

Table 4: Pedal type results when used during first half of test day (Case study 2). Negative values for differences indicate that the EP value is higher

	Power (Watts)	Cadence (rpm)	Heart Rate (bpm) Average
Conventional Pedal			
6-7 mins (90 watts)	94	74	89
9-10 mins (150watts	150	71	111
12-13 mins (180 watts)	180	70	124
15-16mins (210 watts)	209	69	138
Easy Pedal (EP)			
6-7 mins (90 watts)	91	74	89
9-10 mins (150watts	150	72	115
12-13 mins (180 watts)	180	72	129
15-16mins (210 watts)	210	69	145
Difference (Conventional-EP)			
6-7 mins (90 watts)	2	0	0
9-10 mins (150watts	1	-1	-4
12-13 mins (180 watts)	0	-2	-5
15-16mins (210 watts)	0	0	-7

Table 5: Pedal type results when used during second half of test day (Case study 2). Negative values for differences indicate that the EP value is higher

	Power (Watts)	Cadence (rpm)	Heart Rate (bpm) Average
Conventional Pedal			
6-7 mins (90 watts)	91	72	98
9-10 mins (150watts	150	72	119
12-13 mins (180 watts)	180	72	131
15-16mins (210 watts)	210	70	148
Easy Pedal (EP)			
6-7 mins (90 watts)	93	74	103
9-10 mins (150watts	150	74	127
12-13 mins (180 watts)	180	70	139
15-16mins (210 watts)	210	68	153
Difference (Conventional-EP)			
6-7 mins (90 watts)	-2	-2	-5
9-10 mins (150watts	0	-2	-8
12-13 mins (180 watts)	0	2	-8
15-16mins (210 watts)	0	2	-5

4. Conclusions

The aim of both studies was to assess the effects of the EasyPedal prototypes compared to conventional pedals on cycling efficiency. The main study and case study results do not indicate reduced energy expenditure when using the EasyPedal prototypes versus conventional pedals in either a typical cycling set-up or semi-recumbant position. This is based on similar levels of oxygen consumption and heart rate when using both pedal types at the same absolute cycling intensity (measured in watts. However, this does not rule out a potential benefit of the EasyPedal prototype when used at slower cycling cadences (testing in this study carried out at cadences of approximately 70 rpm) or with a novel/alternative cycling pattern. The testing detailed in this report illustrates the acute responses to using these pedal prototypes (i.e. after < 30 minutes of use). It is possible that individuals could learn to perform an altered pedalling style which could make greater use of the potential mechanical advantages of the EasyPedal prototypes. Such an altered style would take time to develop and would change the neuromuscular requirements of the task. It is still unknown how much time would be required to develop such a pattern and what possible advantages it would provide in terms of cycling efficiency

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